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Performance of IGISOL 3

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Abstract. The main goal of the upgrade project of the IGISOL was to increase the yields of the mass-separated reaction products. The first tests showed that the goal was met. Typically, the yields normalized to the primary beam intensity are at least three times higher than before the upgrade. In addition, we have started a project to selectively laser ionize neutral atoms in the gas jet emerging from the ion guide and guide the photo-ions with a radiofrequency ion trap to the acceleration stage of the isotope separator.

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1 Introduction

The ion guide technique was developed in Jyväskylä during the 1980's. In the ion guide the primary ions from a nuclear reaction are thermalized in very pure noble gas where they stay as ions due to the high ionization potential of the stopping gas. Ions are flushed out of the ion guide to a differential pumping section where they are skimmed from the neutral gas with electric fields [1,2].

The success of the method has had a major impact on planned concepts of future radioactive beam facilities, such as the radioactive ion acceleration project at Texas A&M University [3], EURISOL [4] and the Rare Isotope Accelerator RIA [5]. The IGISOL upgrade project was launched after it had become clear that the new ion beam handling techniques such as the radiofrequency quadrupole ion cooler [6] and the mass purification Penning trap [7] would soon make the front end of the IGISOL mass separator the weakest link of the facility. Also, the need of selective ionization techniques such as laser ionization was recognized and technical requirements for such a system were taken into account in the new front end design.

Table 1. Yield of mass-separated radioactive ions after IGISOL dipole magnet for some light-ion–induced reactions.

Ion	Reaction	Beam		Yield	Old	Gain
		MeV	μA	$/\mu$C	yield	
^{12}B	(d, p)	10	11	900	500$^{(a)}$	1.8
^{20}Na	(p, αn)	40	5	100		
^{31}Si	(d, p)	19	4	400	150	2.7
^{46}V	(p, n)	20	5	800		
^{58}Cu	(p, n)	18	1	1500	350	4.3
	(^{3}He, p2n)	50	3.3	320		
^{62}Ga	(p, 3n)	48	35	20	10	2.0
^{66}Ga	(p, n)	22	1	17000	2500	6.8
^{100}Tc	(p, n)	10	6	2300	300$^{(b)}$	7.6
^{209}Pb	(d, p)	13	1.5	3000		

(a) Using 6 MeV protons.
(b) Using 12 MeV protons.

2 Upgrade to IGISOL 3

Proton beams with intensities higher than 50 μA are used for medical isotope production from the K-130 cyclotron [8]. Beam intensities of this order could not have

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previously been delivered to the IGISOL as the radiation level in the experimental area next to the IGISOL cave exceeded 1 μSv/h. In the upgrade the shielding thickness in the primary beam direction was increased by 1.0 meter to 2.5 m of concrete. This has decreased the radiation level behind the shielding below the measurement threshhold even with the highest beam intensities used thus far (see table 1).

In particular the fission application of the ion guide technique has been handicapped by the limitations in the pumping speed. Stopping of energetic recoils in helium gas requires high pressure in the stopping cell, which leads to a higher gas load in the differential pumping stage and consequently requires more efficient pumping. In IGISOL 3 the vacuum chamber housing the ion guide is larger than before. In particular more space is available towards the separator, providing wider pumping channels between the ion guide and the skimmer electrode. Also, the extraction region is evacuated by a more effective diffusion pump (8000 l/s *vs.* 2000 l/s) through wider pumping channels than before.

A larger chamber also allows alternate ways of coupling the ion guide to the separator, such as use of a radio frequency multipole instead of a skimmer. The enlargement of the target chamber towards the cyclotron gives more space for a heavy ion fusion reaction type ion guide.

The higher beam intensities also lead to higher activation of the front end of the mass separator. To minimize the working time in the high radiation area, all valves and electrodes in this area were switched from manual to remote control. The whole separator vacuum system is now computer controlled. The ion guide mounting system was modified so that ion guides can now be changed as complete units.

The first on-line tests were performed with light-ion–induced fusion reactions. Yield data for some recently used reactions at the IGISOL 3 are given in table 1. Whenever a comparison to “IGISOL 2” is possible, the yields per μC are between 2 and 8 times higher. However, many of these yields have been tested only with low primary beam intensities. Although the ion yield has been shown to scale linearly with primary beam at the IGISOL [9], ambitious extrapolations should still be avoided.

In the first proton-induced fission experiments after the upgrade in June 2004 the size and shape of the ion guide, except the new mounting, were exactly the same as in the last fission run before the upgrade in February 2003. Any improvements in the fission product yields can thus be attributed to the changes in the extraction and skimmer region. With 10 μA primary beam intensity the cumulative yields of ^{112}Rh were 18000 and 47000 ions/s in February 2003 and in June 2004, respectively. With 25 μA primary beam intensity this yield reached the 10^5 ions/s level in June.

The primary reason for the improvement in efficiency appears to be due to a better transmission through the extraction electrode. The increased pumping efficiency allows the use of a 7 mm aperture in the extractor instead of a 4 mm one that had in fact been collimating the ion beam. This could be deduced from the surprisingly good emittance of 12 π mm mrad of the old IGISOL.

The emittance of IGISOL 3 has not yet been measured. However, a lower than before mass resolving power (MRP) achieved immediately after the upgrade gives reason to believe that the emittance has increased. After replacing the old dipole magnet with an ISOL magnet from GSI a MRP of 350 could be reached with 400 V skimmer voltage and 300 mbar helium pressure inside the ion guide. This is sufficient to focus the IGISOL beam properly to the deceleration stage of the RF cooler. For $A = 112$ fission fragments a $69 \pm 3\%$ transmission through the cooler was measured in June 2004.

3 The FURIOS project

Despite the fact that IGISOL is a fast and universal method, it lacks in both efficiency and selectivity. To address these important issues, the development and construction of a laser ion source, coupled to the existing facility began in early 2004. The Fast Universal Resonant laser IOn Source, FURIOS, will provide singly charged ions using a combination of solid state Ti-Sapphire lasers and dye lasers. This twin laser facility will provide a good coverage of ionization schemes throughout the periodic table, and the ability to perform optical spectroscopy within the ion guide. Two forms of laser ion source development will be undertaken. These will study both the well-developed intra-source ionization of elements and the high selectivity production achievable with a LIST (Laser Ion Source Trap) [10]. Unlike a conventional laser ion source, ion production in LIST is achieved outside the recoil stopping and thermalization region. The proposed JYFL LIST uses an RF-hexapole trap placed immediately after the ion guide in the gas expansion region. Counter-propagating lasers directed through the mass separator selectively ionize the fast neutral atoms as they exit the ion guide within the effective volume of the RF-hexapole. If successful, this new project will allow future experiments at the IGISOL facility to proceed with elementally pure beams produced at greatly improved absolute efficiency.

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